Army Research Laboratory

Human Purposive Movement Theory

by Bruce P. Hunn

ARL-TR-5954 March 2012

NOTICES

Disclaimers

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5425

ARL-TR-5954 **March 2012**

Human Purposive Movement Theory

Bruce P. Hunn
Human Research and Engineering Directorate, ARL

REPORT DOCUMENTATION PAGE					*Form Approved* *OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**					
1. REPORT DATE *(DD-MM-YYYY)* March 2012	**2. REPORT TYPE** Final				**3. DATES COVERED (From - To)** 2007–2011
4. TITLE AND SUBTITLE Human Purposive Movement Theory					**5a. CONTRACT NUMBER**
					5b. GRANT NUMBER
					5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Bruce P. Hunn					**5d. PROJECT NUMBER**
					5e. TASK NUMBER
					5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: RDRL-HRM-AY Aberdeen Proving Ground, MD 21005-5425					**8. PERFORMING ORGANIZATION REPORT NUMBER** ARL-TR-5954
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)					**10. SPONSOR/MONITOR'S ACRONYM(S)**
					11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The human purposive movement theory posits that human physical behavior is goal oriented, quantifiable, and predictable. In addition, the basic characteristics of that movement are universal in nature by humans whether they are operating on their own or when using conveyances, and that the characteristics of human/machine system outputs are quantifiable and suitable for the creation of predictive algorithms. This theory coupled with fused sensor systems and robust detection and classification algorithms should enhance the understanding of human physical behavior in applied settings and may be suitable to predict human physical actions in military intelligence or other applied settings. This report reviews the basic theory and provides examples of developmental and operational technologies that could use this theory in common settings.					
15. SUBJECT TERMS human activity, prediction of behavior, human algorithms purposive movement theory					
16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Bruce P. Hunn
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified	UU	40	**19b. TELEPHONE NUMBER** (*Include area code*) 520-538-4705

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

INTENTIONALLY LEFT BLANK.

1. Summary

This report reviews the elements of the human purposive movement theory as well as the developmental and existing ground movement detection and identification technologies used to identify targets on the ground in military and law enforcement settings. The systems under review allowed users to detect, identify and classify ground targets that are characterized by locational movement. The goal of the human purposive movement theory is to intuit the movement patterns of targets of interest through sensor systems and then predict what the goal of those targets might be in the future via automated algorithm application.

2. Introduction

The theory of purposive movement was originated by Bruce P. Hunn in 2008 as he was evaluating several developmental test programs involving surveillance systems for the U.S. Army Research Laboratory. As a result of work on the Department of Homeland Security (DHS) Secure Border Initiative Project (SBInet) 2008–2010, as well as other prior and post-surveillance programs of interest to the U.S. Army Research Laboratory, he proposed a unified theory to account for human physical movement and its relationship to human-defined goals.

3. Background

3.1 Theory

Goal achievement behavior has been studied extensively in the psychological domain. The works of E. A. Locke as well as G. P. Latham and other pioneers of goal-setting theory have focused on the principles of human goal setting for over 35 years.

The spectrum of psychological theories associated with goal setting runs the gamut from "prospect theory" (Kahneman and Tversky, 1979) and the establishment of "reference points," to Bandura's (1986) discussions of personality effects. A recent compendium of these works (Locke and Latham, 1990) cites 131 articles dealing with the elements of setting goals from a psychological perspective over the last three decades.

At the other end of the goal perspective—that is, of the initial actions leading to the process of physical goal achievement—work has extended back to the 1860s to Franscus Donders (Wolfram Research, 2012), who studied multiple stimuli and choice reaction times. This area of inquiry was expanded in the 1920s by R. V. L. Hartley (Hartley, 1928), who began to look at actions in terms of bits of information transmitted. This theory was based in the emerging science of electronics and a point of view that was later seized on by C. E. Shannon (1949), who moved it into the realm of experimental psychology as that emerging science was being applied to control and display design. Goal completion was also a popular subject in early industrial engineering and is exemplified by the work of Gilbrath (Gilbrath and Carey, 1948).

On the physical and ergonomic side of goal analysis, the pioneering work of Paul Fitts (1954), Fitts and Peterson (1964), W. E. Hick (1952), and R. Hyman (1953), with the field of choice reaction times, contained some of the first attempts to quantify, in a micro sense, human physical activities associated with goals that were accomplished via human-machine interaction.

Unlike time-motion studies of the early 1900s (Gilbreth, 1910), which were either associated with micro-level activities, such as hand movements, or overall work efficiency, such as bricklaying, the work of Fitts limited the scope of inquiry to the degree that simple rules could be defined for human-machine relationships that involved controls and displays. This work created simple rules of behavior, such as the relationship of response time for a particular control to the parameters of distance to that control as well as the consideration of its physical size. In a similar way, this quantification process led to other considerations, as outlined in the Hick-Hyman law for choice reaction time (1952). This progression in the field essentially sought to quantify the pioneering work of Donder, Hartley, and Gilbreath into a mechanistic, quantifiable approach to human physical behavior.

When these quantitative principles were applied in actual settings, rules of thumb, or heuristics, were generated that contributed to sequence-of-use, criticality-of-use, and frequency-of-use routines that could then structure the design of many types of interfaces.

Considering this theoretical and practical underpinning, the idea of purposive movement is prompting researchers to analyze more complex physical actions in order to relate human physical movement through several micro or macro processes to a final goal. In essence, this approach relates a very long string of complex physical actions to an overall goal in contrast to much of the previous work that related subtasks to secondary tasks to an intermediate goal (like steering an airplane to the right). This approach also considers the complexity inherent in actions that involve numerous players who may play different roles but work together as a team to affect a single physical action.

In this latter regard, the theory of purposive movement is like a fusion of the work of Gilbreth, where overall process effectiveness goals were being sought while relying on the quantitative methods of Fitts. In keeping with the progression in technology since those studies were accomplished, the emphasis in this theory is on the use of fused sensor systems (particularly moving target indicators shown on a geographic projection), computer processing of that data, and the need for an interface system to process and filter that information through automated algorithms before it arrives at the human decision maker.

3.2 Refinement and Discussion of the Theory

With all this literature that examines and refines goal-oriented behavior, there has been little work associated with the simple physical acts involved in completing those goals (other than the pioneering work cited previously), an omission that tends to infer that most researchers have focused on goal-oriented behavior within the domain of cognitive motivation and cognitive procedure. *The theory of purposive movement views human action as a physical activity product, not a psychological process,* and that perspective requires physical, quantifiable measures. The assumption is that numerous cognitive precursors, while required, cannot be intuited and quantified as easily as their physical domain steps to a goal. An analogy is as follows. A travel vacation organized, planned, and budgeted is not a vacation until the originator physically moves from one location to another. It is this movement that can be quantified and processed through various algorithms in order to reach a goal.

This new approach also implies a mechanistic view of human behavior that can quantify complex actions into their simplest common denominator, physical activity.

Our first premise is that any physical goal completion must be accompanied by physical actions; the analysis of those actions alone is the primary basis for the following discussions. This approach creates an engineering model that can be readily quantified, where each step at either a macro or micro level can be input to a predictive model. By eliminating the discussion of the cognitive aspect of goal completion, we can more readily model the ability to analyze and predict goal behaviors. Once modeled, these behaviors may be input to an automated digital system where outcomes can be intuited at rates considerably faster and using more variables than can be managed by the human mind. This system does not eliminate cognitive elements or human judgment but merely accelerates the process at which complex information can be categorized using current state-of-the-art tools.

We have mentioned goal completion in this discussion; however, the element of shared goal completion is also critical here and in many ways makes the process more intuitive as well as more sensitive (information rich) in terms of quantitative assessment. For example, if a football team is seeking a goal, each member will work in a concerted process to reach that same goal. This redundancy in information content (players working together) provides a powerful multiplier to the ability to predict a single outcome, whether that is to attain a goal or win a game.

The idea of shared goals for this discussion is being represented as a didactic comparison as viewed from both sides of an action. In other words, to use another sports-related analogy, for any event there must be a winner and a loser, assuming both participants play to win. If we assume a shared goal of winning, and we assume that each side wants the same goal, then we can assume that while both sides will try to win, there can ultimately be only one winner (of that goal). The modeling of the actions that contribute to winning when considered from a "purposive movement perspective" uses physical processes inherent primarily from one side and analyzes them in a quantifiable way in order to predict an outcome. In some regard, this is like a war-gaming process. Consider that a war-gaming scenario places opposing forces on two sides of a logical argument, using fixed variables such as the numbers and types of weapons, numbers of vehicles, numbers of personnel, qualities of personnel, etc., and then that war-gaming process attempts to subjectively determine equivalency or superiority. While this approach may be effective in conventional force engagements, it is not the most suitable approach when considering asymmetric actions, particularly if those actions are those of individuals or small groups.

During this discussion, the physical behavior of single personnel, groups of personnel, personnel using conveyances, and any types of living entity movement systems are considered. Each of these issues will be discussed in later sections, but in order to explain the overall thrust of this argument, the following examples will be presented.

4. Methodology and Procedures

4.1 Contextual Examples of the Theory: Tactical and Strategic Analogies

Consider the following military situation: a particular target is selected by an enemy force for attack. In order to accomplish that attack, the enemy must organize its forces physically, then transfer their physical positions from dispersed locations to the target location. Assuming that 30 enemy fighters are involved, each of those fighters must move from wherever they are located to the target. In many military operations, that physical movement can be, or is, monitored by sensors, and that sensor feed is the core, or primary input data, for trying to understand what their goal might be. Most ground- or aerial-based surveillance systems using ground moving target indicators (GMTIs) can track such personnel movements, but to date, no comprehensive automated algorithm has been created to tie these separate, seemingly unrelated physical movements together to address a future threat. That chore has fallen to an image analyst at a fairly low level of management—in the case of a law enforcement action, an officer or detective, and in the case of a military operation, a private or lower-level enlisted person. This approach will supplement those personnel's activities by sorting, organizing, and manipulating data being received at thousands of bits per second into a form that may be readily understood by relating it to known target locations.

While it seems obvious that an army must move in order to fight, little work has been done to proactively predict the possible goals where small numbers of personnel are involved. So, for example, an army of 200,000 on the march needs little analysis to ascertain likely goals—their goals will clearly be tactical or strategic—and it is relatively easy to determine outcomes when they are matched with conventional forces of any reasonable number. These traditional war-fighting analysis approaches have been extensively modeled based on large-scale applications usually at strategic and sometimes tactical levels; however, the drawback to those approaches with small-scale operations is that a single individual or very small group of individuals has shown by recent terrorist acts to be capable of creating a reaction much larger than even a conventional military force by using novel tactics or weapons of mass destruction, or by acting through isolated/stand-alone cells that perform “in the dark” in terms of observation by larger, better-equipped forces.

To demonstrate with another analogy, the launch of a missile follows a fairly clear ballistic (hence predictable) trajectory, and the speed and direction of that missile can quickly be equated to possible targets through radar sensors. However, how can the action of one or two terrorists in a large city be predicted? What is needed is a method by which the direction and goals of individuals or small groups can be predicted with the same accuracy that a ballistic missile’s path and target can be predicted.

It was the experience and observation of physical actions conducted in operational field trials of surveillance systems that indicated that the potential to predict future activities of such actors was not beyond current technical knowledge. It was, in fact, demonstrated during recent testing that merely being made aware of the existence of hostile or illegal personnel in the field through various sensors did not by itself lead to increases in effectiveness in their apprehension (Hunn and Schweitzer, 2011). In part, this was the case because the classic cognitive assumptions of enemy vs. friendly interaction do not provide a suitable edge to the friendly forces over that held by an enemy that was resourceful and capable of both free movement and evasion. It is suggested that some of the intuitive human intelligence processes that *were observed* during recent tests had value in acquiring and classifying human targets and could be automated with existing technology to better understand and predict future goals.

Limitations to current strategic and tactical thinking in these and other force-on-force applications are that the study of the *variables* that affect human actions tends to move toward the infinite rather than the finite, particularly in the psychological or cognitive realm. The quantification of such variables to affect an action or change is essentially impossible because the endeavor tends to become either a “what if” situation with limitless possible outcomes or a guessing game where one side “assumes that” the opposite side will perform in a certain way. Both of these methods are quite unscientific and imprecise in their ability to predict what an assailant’s goals might be.

Historically, to compensate for this challenge, enormous intelligence and training are both required so that the intentions of an enemy may be intuited; if their goal trends can be intuited correctly, then a successful counter physical action may be waged. This approach is problematic in many regards because it creates a situation where one side attempts to intuit highly variable behaviors and then “walk a mile in the shoes” of the other side in order to predict an outcome. This becomes much more difficult when the aggressors are few, the “neutral players in the field” are many, and the sources of intelligence data are typically highly subjective.

The biggest problem with this legacy predictive approach is that the effects of a technologically advanced attack may make the cost of waiting until enough attacks have happened in order to form a pattern very counterproductive. In contrast, the number of physical paths available to take to a target can be easily studied and modeled. What will be observed in the discussion of this theory is that the concept of "satisfying goals" through a relatively small set of "the most likely probable physical actions" will be made vs. a nearly infinite set of "possible events driven by cognitive or subjective values." Also, it is suggested that this may be a more logical way to proceed in intuiting future potential actions.

Another problem with the legacy processes is that cognitive variables are by definition isolated within an individual or individuals, and their extraction and future direction is fraught with risk and uncertainty (high variability). In the case of the "fog of battle," it is almost obvious that intuition or the ability to predict future events is mired in physical circumstances that may quickly change the tide of the action before a cognitive solution can be intuited by the opposing force. It is suggested that a simpler mechanical- and engineering-based approach be tried, using the power of automated, computerized routines (algorithms), and that the primary metric of physical actions be coupled with remote sensing systems.

A further analogy can be made here: it is as if a fighter pilot had no radar (a quantifiable digital system of sensing) and instead relied on his eyes alone to detect an incoming enemy. In that situation, no pilot could hope to have the visual acuity, the reaction time, and the cognitive capability to hit an enemy aircraft before it could destroy his aircraft. Many intelligence agencies are now facing this situation—they lack high-speed decision-making aids to make judgments. Rather than using quantifiable numeric criteria, they substitute intuition or historical precedent.

4.2 Field Studies That Contributed to the Theory

During the DHS SBInet project test, a fused sensor system consisting of electro-optical video cameras, infrared video cameras, ground-based radars, and underground sensors were all integrated to a central command and control facility called "the COP" (Common Operating Picture). This system was evaluated by Mr. Hunn and associates from the U.S. Army Research Laboratory and other U.S. government organizations. U.S. Border Patrol agents manned the COP in operational as well as test situations. The area chosen for observation was an active, open, and unrestricted plot of public and private lands (about 500+ square miles) adjacent to the U.S. southern border in Arizona. The area under consideration acted as the official border between the U.S. and Mexico and as a close-to-the-border test range that had been instrumented with various sensors and patrolled by U.S. Border Patrol officers.

Driving the purposive movement theory were observations of the behavior of ambulatory and vehicle-borne personnel consisting of drug smugglers and illegal immigrants as well as test subjects who attempted to evade the sensor systems of the SBInet and field Border Patrol agents in a complex rural-terrain environment.

Parts of this test overlapped with active law enforcement operations (resulting in arrests of lawbreakers) while others, like the behavior of test subjects, were either highly scripted (certain routes were to be followed) or free-play, i.e., reasonable countermeasures could be used by participants to avoid capture during the test. In both real and artificial scenarios, the goal was to evade capture by Border Patrol officers and traverse a large rural area to reach a "safe goal location." In many cases, this included traversing 5–13 miles of terrain by foot or by vehicle using either trails or nonsurfaced all-wheel-drive roads.

Conceptually, the personnel located on the ground walking and driving vehicles formed the input variables in a very complex game where their purpose was to evade both ground personnel sent to interdict them physically and the sensor grid designed to detect them electronically. In cases where actual illegal acts were being committed, the incentives for participants to evade members of the U.S. Border Patrol included avoiding jail, deportation, as well as possible death or physical harm should they return to Mexico and face drug cartel retribution.

For the scripted test points, trained test subjects (Border Patrol agents) would suffer no negative consequences; however, their competitive spirit precluded them from being captured easily. The spectrum ranging from serious results from capture (for real lawbreakers) to no significant negative results from capture (for test subject agents) provided motivation and incentive for all participants.

Based on several years of observation, testing, and interviews with field and supervisory agents, certain elements of human behavior were considered by the author as indicating that movement of human personnel under these conditions might be modeled and incorporated into a theory that could expand to include other venues than the one being tested.

During the time of test, numerous events contributed to this theory's elements and allowed abstraction of field characteristics of humans to be thought of in a more structured way than revealed by their individual performance behaviors on this test alone.

4.3 Elements of the Theory Derived From Test (Macro and Micro Goal Achievement Factors)

When the previous test situation was analyzed, in order to assess the effectiveness of the combined electronic sensor effectiveness as well as traditional observation and interdiction measures, common threads emerged that led to the theory of purposive movement. The following discussion examines some of those points, which are what the author would categorize as "macro factors" or large-scale elements of learning and behavior observation derived from the test.

1. All behavior exhibited showed trends of goal satisfaction either in the macro or micro sense from physical movement. For example, for either drug trafficking or illegal alien smuggling, the goal was to pass undetected through a gauntlet of sensors and agents to safe points beyond the border. In most operational cases this implied transits of ~30–50 miles,

while for test cases the distances were typically 5–13 miles. As part of achieving this overall goal, the purpose was to remain undetected by COP monitored sensors and law enforcement personnel or residents who might report the presence of illegal persons to the authorities. Thus one macro goal of all participants (both test and operational) was to avoid detection. In the case of border evasion techniques, one conclusion was that movement in all cases resembled a northing trend in order to be effective—that is, to move north from the border was a mandatory requirement of that macro goal (even if east, west, or southern movements were required to meet micro goals).

2. Another factor was the use of established trails and roads that had formed a historic subset of routes that predictably could be relied on to create a smooth flow of participants toward their goals. This was in direct contrast to cross-country travel using no trails or roads, which was not typically observed.

3. Time of day or night common for the traverse was to reduce fatigue from desert heat or to decrease the possibility for simple, unaided visual detection by agents or concerned citizens (i.e., travel at night). Also, the time needed for transit from the border to safe areas was fixed by the rate of speed that could be sustained by the traverse method and location chosen.

4. Movement speed was based on many factors: terrain, temperature, and number of participants, conditions of day vs. night, physical loads carried, physical condition of participants, and availability, or lack of, water or a suitable supply of food on a particular route.

All in all, this test environment strongly resembled that of a military operation—the major difference was that a singular terminal point goal was not fixed (except in the case of specific locations required for drug drops). However, as an experiment, this scenario created lessons learned that could be extrapolated to military venues.

4.4 Further Test Scenarios Discussed (Micro Goal Achievement Factors)

The common themes derived from these tests were that almost all behavior could be analyzed in the same manner—that is, by defining a goal (going north), observing physical activities leading to that goal, and then completing and extracting the common principles that define that goal's acquisition regardless of whether it was at the macro or micro level.

At the micro goal level (the level that contributed to macro goal achievements but was a relatively minor overall measure), various tactical measures were employed, including travel at night and travel using the concealing features of terrain, camouflage, deception, and evasion techniques, such as obscuring foot tracks, splitting groups on interdiction, changing routes, etc. In general, these behaviors still demonstrated the goals of the participants via different physical movement applications. This included situations where vehicles were used to the same purpose.

These subelements, or the micro features, of that goal were often situation or terrain specific; for example, in the overall test area, the normal walking speed is usually not over 2.5 mi/h on foot. Motivated, well-trained, and well-conditioned personnel could walk the same trails at 3.5 to 4 mi/h and sometimes faster when using artificial stimulants, such as those used by drug runners in this area. However, regardless of the rates of movement when tracked by radar, all the targets showed the consistent use of established trails that were previously marked by GPS tracking systems. In other words, these trails were well known by both illegals and law enforcement personnel. Their use was a typical and practical way to traverse areas containing hazards, such as cactus, or impeded by physical obstacles, such as rocks, boulders, ravines, cliffs, forest, scrub, and mountains. It is also interesting to note that almost no cross-country, non-trail, non-road activity was detected, except for short time segments of cross-country scattering that occurred when groups dispersed when being apprehended. In many cases, these groups subsequently regroup on adjacent trails, roads, or at known landmarks in proximity to the dispersal site.

One prominent micro goal was a well-known apprehension avoidance technique named by the Border Patrol as "going south," where personnel returned to the safety of the Mexican border, regrouped, and tried again at a different time or location. This type of behavior clearly indicated their future goal of going north by the flight directly south to safety.

Other micro goals used by more sophisticated smuggling groups have well-established contingencies for dealing with interdiction. These contingencies involve dropping contraband, firing weapons as a lethal or pseudo-threat, providing decoy personnel, or splitting up and meeting at a prearranged place or time.

During the test, each route that was accessible to radar could provide a record of human ambulatory "micro" movement as individual radar targets presented to COP operators on COP display terrain maps. Each target and group of targets could be designated for movement velocity, and those results would be indicative of the type of target as well as representative of a classification scheme informally tallied by the operators into categories such as illegals, drug runners, friendlies, or unknowns. In many cases, the COP operators, through their experience, could determine a type of target by its physical behavior alone; again, however, that was not formally incorporated into a theory, model, or algorithm of human physical behavior.

4.5 Additional Information Contributing to a Model of Human Physical Behavior

The detection and interdiction data indicated in the SBInet test showed that each type of "nonhuman target" also had certain predictable physical characteristics.

Open-range cattle that were present in the test area have been observed to follow spiral movement patterns when grazing (Senft et al., 1983). Their grazing movement pattern is also influenced significantly by humidity, sunrise time, slope and aspect angle, food type, and slope qualities (Roath and Krueger, 1982), all of which represent repeatable patterns that in this case are counter to the target human population patterns. In their way, the purposive physical patterns of cattle movement form a distinct subset of behaviors that can classify by type, animal vs. human targets. This was also recognized by the agents in the COP.

Other examples include cattle following a lead cow as a group, cattle moving rapidly as a group (stampede), or cattle grazing as a group. COP agents intuitively understood these patterns, but these behaviors were not formally integrated into a model or theory of behavior that might formally classify target types. Rapid cattle movements often indicate human presence—a “rule” that was defined by the agents but not formally incorporated into the system. This was refined to the point that any rapid cattle movements in one direction prompted Border Patrol agents to scan in the opposite direction of the initial dispersal area to see what had caused the cattle dispersal. In some cases, the movement of the herd was instigated by humans approaching that herd.

Other animals observed also had characteristic movement patterns; for example, horses, deer, and javelina exhibit grazing behaviors that are similar to, but not quite the same as, cattle. Individual (non-herd) animals, such as coyotes, bears, and rabbits, have respectively different hunting or foraging patterns that are characteristic of each species. These patterns were observed and intuited using electro-optical sensors, infrared sensors, and radar and underground (seismic) sensors with varying degrees of success based on sensor type.

Radar targets created by returns from personnel and vehicles could also be manually separated from returns caused by fixed objects moving in the wind (trees, leaves, brush) as well as moving objects that also provided “random returns,” such as rain, dust, blowing leaves, etc. The agents intuitively recognized that an object traveling cross country over high-relief terrain at 10 mph could not be a human, just as objects traveling 10–30 mph would automatically be classified as a bird or a bat. During the testing period, several aerial unknowns were identified that may have been ultra-light aircraft, but their consistent maintenance of airspeed at +30 kn would then separate them by further classification as a non-bird, non-human, and non-ground vehicle. Conversely, such ultra lights were further discriminable from regular light aircraft by their extremely slow, linear air speed (contrasted to 100+ mph for small fixed wing aircraft). In the same way, helicopters provide certain unique flight characteristics (non-linear flight in comparison to fixed-wing aircraft of any type).

It was observed that there were purposive direction indicators of aircraft movement by their human operators even if those operators were controlling the aircraft remotely. That pattern of control of an air vehicle is not the same as the movement pattern seen in flying animals (birds, bats, insects, etc.). It was further observed that the particular pattern of flight was very much a series of straight lines as demonstrated by navigation from point to point, which is not similar in any way to the natural flight of animals or other flying creatures.

In the same way as animals could be classified by their physical behavior, wind movement created false radar signals that mimicked a large group of people moving on the ground; however, with extended observation, that movement path would reveal itself as a wind front because of its lack of significant change when traversing rugged terrain. In general, many indicators of object and human movement were intuitively understood by the COP operators but were not incorporated into any formal model or movement predictive routine. Simple algorithms built into the COP radar system separated personnel from vehicles by sustained movement velocity comparisons.

The focus of this discussion is that the extraction of both human and nonhuman physical movement characteristics could be implemented into a robust algorithm that would detect and classify unknowns into known targets. Certain radar systems under development have already incorporated “distinct movement patterns” into algorithms to separate one type of signal from another. The theory of purposive movement recognizes these “micro-level algorithms” as a necessary precursor toward a macro version that works on a tactical or strategic level.

During SBInet testing, other false positive radar targets were generated by metal objects that were fixed in position but moved with the wind—specifically, metal signs, loose metal siding on buildings, and cattle-watering windmills. These objects all created distinct patterns that mimicked human-caused radar patterns; however, they differed significantly once COP operators gained skill and experience derived from multiple observations and applied that experience to those radar returns. The simplest, most intuitive discriminator of these events is that they were fixed in a location and, not being ambulatory, did not represent logical human physical movement in space and time. The only possible confusion that they may have caused was the unlikely event of a person or persons standing in one place and waving their arms or some other objects, thus creating a distinct localized signature.

Time-associated micro-level patterns of behavior were also noted in the case of moving or grazing cattle, which occurred at approximately the same time and location every day. In some cases, operators were so confident that a particular set of radar returns was cattle, that they would ignore those radar target returns altogether.

Interestingly, some of the same human physical behaviors were duplicated when target personnel drove vehicles through the test range. For example, vehicles with real illegals in control typically did not drive exceptionally fast; they kept a low-signature dust profile, avoided headlights at night, and abandoned their vehicles in the exact same way that ground-based groups disperse when interdicted by the authorities (they scatter randomly). In general, both illegal and test drivers followed known roads or trails and did not deviate from established pathways known to them (typically, both target and Border Patrol drivers were experienced and have traveled the same routes many times). Thus even when vehicles were used, the basic macro pattern remained, and some of the same micro patterns of evasion as well as apprehension were used by both sides. In other words, human ambulatory patterns were repeated when humans drove vehicles.

4.6 Military Intelligence Implications and Moving Target Indicator Technologies

These operational and test situations resulted in an abundance of data on human physical behavior during illegal border-crossing activities as well as structured test scenarios. Another source for this data was encountered by military operations using Moving Target Indicator (MTI) sensor systems and algorithms. These technologies have been used for years in military settings to understand human physical movement as well as vehicle and even aircraft movement in order to intuit purpose and meaning that may have military implications. Some of these same technologies for GMTI systems were also used in the SBInet and are being used in experimental and production surveillance systems operated both from the ground and from the air. Commonalities include the ability of radar, in particular, to determine movement speed and direction for everything from personnel on the ground to low-flying aircraft. Other capabilities include active tracking, target designation (out of a large set of many possible targets), and movement change detection for both ambulatory and fixed objects. Most systems now in use have recording capability and multisensor surveillance inputs. In general, these systems use Doppler radar as their primary technology for movement detection.

Currently, friendly personnel are distinguished from aggressive or neutral personnel by visual observation on the ground, radar signature on the ground or in the air, or ground-based systems, such as the "Blue Force Tracker" (General Dynamics, 2011). (Blue Force Tracker [BFT] consists of transmitters attached to friendly personnel and equipment to distinguish them from other hostile or neutral targets.)

In the case of observation, visual and identification criteria are mostly held in the memory of the field agent or, in the case of the SBInet, by the COP operator. In the case of radar signature in the air or ground, only limited and lightly automated criteria are used in current systems. In the case of systems like BFT, the coding of friend or foe is limited to whether the transmitter is properly attached to a "real friendly" and has not been taken and used in a deception role, thus physical security of the BFT is critical to its success. Including BFT-coded objects on COP-style observation screens is highly encouraged to increase the operator's situation awareness of who is afield. Similar systems have been used on aircraft to distinguish friend from foe.

While the BFT is very useful in discerning friend from foe, it is unlikely that the foe would submit to such a targeting scheme as BFT, hence the need for a more robust but unobtrusive tool to classify targets and thus intuit intent. The use of purposive movement may be such a tool once implemented into a robust multi-tier classification algorithm. Digital processing of multiple and recursive behaviorally based algorithms may be the solution to this issue, hence the first requirement is for a method that could define future detection algorithms.

The following examples may better clarify how the theory could address various likely scenarios.

4.7 Example One: Foot and Vehicle Traffic Observation in a Military Setting

A common scenario in an asymmetric warfare environment is where the majority of targets are "noise" in terms of signal detection. That is, they are friendly or neutral targets that are engaged in normal, legal activities. In an urban environment, shopping, marketing, business, and recreation are all examples of activities in which neutral targets are engaged, and they will always be the primary targets detected by MTI-type systems. Another appropriate analogy is like current airline security checks, where millions of travelers may use the airline systems, and the likely hood of detecting a terrorist is millions to one. This is a real-world example of an asymmetric campaign, with huge numbers of false alarms, false positives and misses, and very few hits (apprehensions of real terrorists). One could argue that the human-based interdiction and inspection of millions of non-targets is an extremely ineffective means to detect a handful of possible real targets, particularly when the detection process is random or selectively subjective or backed by limited "sensor" technology. For example, the unintended consequences of randomly x-raying millions of people will over time (health issues, political dissatisfaction) become a significant counterpoint to finding a handful of possible terrorists. The reason that this current approach is used is twofold: the dramatic human, political, and economic consequences of an airplane crash, and no better process has been implemented.

While the odds are much better of encountering a combatant in an asymmetric warfare situation than on an airline, the odds of finding a combatant in a crowd may be one in a thousand or perhaps one in one hundred ranges. Specific ratios are unimportant if the degree of predictive variables can be matched to a robust system to separate the real from the false targets when those predictive algorithms can be processed by a computer. This type of automated detective work is ideally suited to algorithmic processes.

In the SBInet scenario, false targets included not only animals, but also Border Patrol agents, residents (ranchers and tourists), truckers, hunters, motorcyclists, bicyclists, hikers, and anyone with a valid need to proceed through the area under test. In a military or law enforcement scenario, the game is the same: numerous non-targets for every valid target.

4.8 Example Two: Suicide Bombers and Improvised Explosive Device Emplacers

Improvised explosive devices—in particular, personnel-mounted explosive devices (suicide bombers)— have been an elusive target in terms of detection, primarily because the suicide bombers are making the ultimate sacrifice to achieve a purposive goal and thus are willing to do anything to ensure their success (and their destruction). Under these circumstances, physical behavior (as evidenced by psychological observation) may provide muted cues in order to provide camouflage for their activities until it is too late to stop them. In the same way that the illegal alien drivers would typically drive responsibly in order to minimize their detection, (either individually or within a group of other vehicles), detecting physical behavior characteristics of suicide bombers becomes a real, difficult challenge.

Often this resolution of intent is provided by physical measures not associated with physical behavior directly, but as a secondary micro physical measure such as a biometric. Biometrics, such as facial recognition, heart rate, breathing rate, sweat production, radiant heat output, and pupil dilation, can provide a sensitive, but intrusive, measure of intent if the outcome of that event can trigger a physiological response from the participant. This approach of micro-level biometric measures could also be incorporated into a purposive movement analysis system; however, it would be more valuable if the majority of biometric systems could be made less intrusive. Certain technologies, such as facial and whole body scanning systems, might have application in these scenarios, along with any physical body features that might be diagnostic.

4.9 Example Three: Accompanying Physical Behavior Precursors

Certain events that immediately precede goal completion may serve as nearly instantaneous trigger variables to complete the purposive movement goal completion cycle. An example of this in a military sense as well as the intelligence sense is the use of physical objects to help fulfill that goal—for example, drug packages, bombs, or weapons. Each goal facilitator has telltale signatures that could be exploited and may affect physical movement criteria used as discriminator variables.

In Border Patrol observations, the size and shape of a backpack is highly indicative of its contents. Agents use backpacks as a discriminatory variable to classify drug smugglers vs. nonsmugglers. This classification extends to the postural, physical position of the bearer of those packs because of the weight carried. Many agents during SBInet testing could identify a drug runner even using very poor video imagery by the angle of the bearers back when they were traversing terrain. In addition, the agents also knew that the rate of “persons of interest” travel was proportional to the load they carried.

Weapon possession (long arms in particular) was an easy-to-identify “precursor” prior to weapon use, with possible confounds provided by contextual issues such as would be present with hunters or other Border Patrol agents roaming the field. The type of weapon provides clues to origin, effectiveness, and possible intent—for example, an AK-47 for a drug runner vs. an M-4 carbine for a Border Patrol agent. In many cases, secondary issues, such as group size, traverse rate, number of pauses or rest stops, direction of travel, and scouting behavior, could provide discriminatory variables that contribute to the resolution of intent for that unknown individual or group in a border control situation.

For suicide bombers, secondary scanning systems using microwave, radar, or IR sensors, as well as visual review of their appearance, can provide clues on concealed explosives attached to the body but hidden under clothes. Visible signature items include unexplainable bulges, blocky object protrusions, awkward posture, gait, or stance, as well as electronic differences, which are measured by changes in reflected light, heat, or radar returns from their bodies or clothes.

In terms of detection of precursor events, behaviors like using a cell phone, running, waving of arms, taking a shooting stance, stooping, bending, or falling down may all be immediate precursor behaviors indicating aggressive actions. In all these cases, immediate counter responses would be necessary to preclude successful completion of any aggressive action by that individual. There are also more subtle physical precursors prior to a physical attack, and while largely culturally based, there are some universal human characteristics that could be input to a model that could use aggressive physical actions as precursors.

In the aggregate, crowd behavior, grouping, movement flow, absence of normal gatherings, or notable changes in human behavior have all been used informally to predict events that indicate aggressive actions were about to occur. In particular, with bomb use, indigenous personnel may be informed of pending events and respond accordingly by absenting themselves from the target area. In terms of algorithm creation, a simple geophysical mean density of bodies per unit area could be used as a discriminator tool for urban operations, where indigenous personnel are part of the attack or collateral damage scenario.

A precursor common with vehicle apprehension situations in a law enforcement scenario is the tactic of trying to outrun the apprehending vehicle. This reaction is considered evidence of guilt and is widely recognized as a tool that, if included as an input variable for an algorithm, would have high face and content validity with agents and personnel familiar with its use. It is the same as the acknowledgement of the flashing light seen in the rear view mirror, with which the ethical driver typically signals compliance with the law by pulling over and stopping. This is also a precursor to another series of micro events, such as if the driver jumps from the car and runs away, or if the individual exits the car and approaches the apprehending vehicle and officer. In this latter example, that behavior can lead typically to several outcomes categorized as an appeal for help, a moderate risk confrontation or a serious attack precursor. Typically, the direct physical and close proximity of one individual unknown to another (regardless of cultural norms) accompanied by limb movements is usually a red flag of aggressive intent of varying degrees.

In all these examples, physical movement is goal directed. While such movement is well recognized through the examples shown, it has not been integrated formally into a system that could automatically classify intent based on field knowledge that was quantified and input to a theory and then a model.

4.10 Group and Individual Physical Actions

Complexity evolves as the number of players increases; the rules become more complex, and the stakes or motivation levels fluctuate. However, when the purposive movement approach is used, many of the complex cognitive variables that are concomitant to those actions are not considered; rather, only the physical actions taken to achieve the goal are considered. In this scheme, contributory variables are not considered the critical, primary measureable variables that can contribute directly to the goal at hand. In the case of the SBInet testing, larger issues, such as sociological conditions, politics, individual capability, and limitation, are not considered; only goal-directed behavior that can be simply and physically quantified is considered important to a simple predictive or classificatory system.

Take, for example, the suicide bomber whose goal it is to blow up a target. While an analysis of their emotional state, education, and background might be useful in some sense, the only real utility in a predictive model would be to determine exactly when and where that aggressive act most likely would occur and to determine precursor movement–related criteria that have a valid predictive value.

Much like a multivariate regression model that sheds variables as their co-relational value matches existing variables, this theory/model approach aims to winnow out the variables of minor effects and determine what physical actions are necessary to complete the goal. If we assume that goal fulfillment consists of a simple series of actions, such as (1) walk to police station, (2) enter, and (3) set off bomb, then looking at predictive variables that are purposive and directly linked to that outcome may be an effective prediction method.

While it is difficult to examine complex systems on paper, consider the following illustration of a multiplex algorithm that uses purposive movement as a criterion decision variable. An if-then decision table would have to be built along these lines and then implemented into a manual decision aid or automated into a system that had remote sensing capability providing the input variable responses.

4.11 Conveyance-Based Algorithms

Previous discussion has focused on personnel on foot—individually or in groups—with some mention of other objects that may be found in the same area that could confuse an operator because either they have similar movement characteristics or they exhibit movement in general. Part of the theory of purposive movement also holds that humans operating conveyances often follow the same patterns of movement when operating those conveyances as they do when operating in an ambulatory fashion (for example, the use of cars or motorcycles).

It is also part of the theory that patterns of movement are indicative or reflect the characteristics of the conveyances themselves, and thus those patterns of movement are suitable for modeling. So even with a human operator, the movement characteristics of a conveyance would be modeled. This might be as simple as a person riding a horse, mule, camel, or burro, or as complex as a multiwheeled truck, train, or tracked vehicle. The assumption presented is that each system of conveyance reflects the will of its operator/rider, whether that system is a donkey or a battle tank. The same analogy could be extended to flying vehicles, watercraft, or ships.

By understanding the movement characteristics of each conveyance, we could use an algorithm to provide better predictive capability than by intuition or guessing on the part of an operator of a fused sensor system. In the simplest sense, we can use the following example. If a target is approaching a goal, the movement characteristics of that conveyance can be analyzed just as easily as was done for individual ambulatory movement. A conventional automobile can move, negotiate turns, and accelerate within well-known parameters, just like a motorcycle or a tank. These qualities of movement could be listed as acceleration rate, turning radius, average speed, or top speed, each of which is a predictive variable. In addition, each type of vehicle can traverse various types of terrain at various rates, to a limited degree or not at all. Simple geophysical databases can identify the different types of terrain, such as soft sand, prepared pavement, and known grades. Such databases can also recognize the ability to cross boulders, walls, bridges, and other rough terrain features, or ford or float on watercourses, or maneuver between existing buildings or in confined spaces.

Each movement variable can isolate the conveyance's inherent characteristics and thus be used as both predictive variables and clues to possible intent—for example, a vehicle-borne car bomb vs. a drive-by shooting on a motorcycle. While the destructive qualities of armored vehicles are obvious, their limitations in turn radius and their inherent width, height, and weight also limit them to use in certain pathways that could also be identified through an algorithm.

Observations by research and border patrol personnel recorded the operating characteristics of pickups and cars during this theories formulation. The same information gleaned from operating specifications (engineering data) or from field observations would suffice in creating algorithms for any type of conveyance that fit the operating characteristics of a particular theater of operation. Input from system experts would provide the best guidance as to what they will do and how they will perform in real-world applications suitable for modeling.

4.12 Example of a Tactical Use of the Theory of Purposive Movement

The following scenario is an example of an aerial-based observation system (an unmanned aircraft, for example) that has sensors of any type that can distinguish ambulatory or individual body movements. This system, which can record a significant area of interest, is deployed over a small city. In this situation, we have 500 to 5000 active "potential attackers" on the city streets. Within that set, we have a subset of 500 personnel in a critical area of regard. In addition, we have a target location terrorist goal, which is a police station. The task is to discern if a terrorist is intent on attacking this target. The core of this exercise is to build an automated tracking algorithm that can discern physical behaviors that may precede an attack.

If we take the target and determine a short- or long-range area of interest around it, then each individual ambulatory "potential attacker" can be rated not only by proximity but also by direction of travel and closure rate to the target. This will result in many determinations—of 300–800 possible attackers, perhaps only 50–60 are in the user-defined proximity or have an acceptable closure path or rate to the target. However, we now have multiple discriminatory variables that are being tracked for each "potential attacker" of interest.

The next step might be to better define each variable of interest. Direction is most easily defined by compass bearings, while position is easily defined using degree minutes and seconds or a simpler zonal approach based on user-defined criterion. Speed of approach could classify ambulatory or conveyance systems rapidly. In the same way, rates of closure changes might also indicate changes in motivation or the receipt of information relevant to the target.

We might also consider secondary classification systems with, for example, user-defined zones. In this sense, proximity might be defined by attack mechanisms, such as sniper fire (1000 yd), controlled rifle fire (300 yd), automatic weapons fire (100 yd or less), close-range rifle or pistol fire (50 yd), grenade or pistol use (10 yd), or knife or small suicide bomb use (feet or inches). Each zone represents realistic limits to characterize specific actions, and each serves as a sequential algorithm trigger. This refinement would only apply as the possible target met predefined criterion based on distance from the target.

Perhaps further analysis of this hypothetical danger reveals that only 10 personnel are accomplishing physical movement that results in appropriate closure rates to the target (appropriate rates as defined by the users—for example, aircraft travel, car travel, motorcycle travel, or bicycle or foot travel rates). Of the subset of 10 potential attackers closing on the target, each path can be recursively examined in real time to show origin and deviations from closure path or changes in closure rate (to consider evasion techniques). However, even with evasion techniques being employed, closure must be achieved to accomplish the mission. That closure criterion variable can discriminate an aggressor from a friend at several levels of classification.

Of course, the closure rate or closure path alone is still not indicative of intent. For example, if a grocery store were located next to the police station, many people would be expected to converge on that location on a regular basis. In that case, the criterion might include tabulating the patterns of the regular customers and then extracting those personnel from "others" that might seldom go to that location. This concept is very much like regular detective work, where an observation is followed by other criterion, but the advancement of the purposive movement approach is that the process is conducted by a machine that can handle hundreds or thousands of variables at once.

The next step is to assign critical triggers to events that are meaningful when viewed from the perspective of the terrorist. Like the use of tools to accomplish the mission, the following examples could be secondary triggers in the prediction and classification approach. An example might be the strength of the bomb that the terrorists are carrying, which in turn drives the proximity that they must have in regard to the target. For example, a grenade has a very limited range, whereas 20 lb of plastic explosive surrounded by nails has a much greater range. This type of criterion could be used to separate a vehicle-borne bomb threat from a hand-carried bomb and to determine critical approach distances for both. This proximity analysis could even be used for roadside bombs that have measureable blast radii. The utility of this system is that no physical action can be accomplished without the physical presence of an agent, and if that agent has a presence, then he or she must leave a trail from origin to goal and show traceable and predictable characteristic movement patterns. It is wise to not focus exclusively on what personnel may be carrying but more on the vulnerability of the target to any likely weapon attack.

As discussed before, the derived algorithm for identifying real threats from non-threats should also be recursive; for example, proximity to the target could be a multi-tiered approach defined by distance in miles, meters, or feet. Defining differences by proximity zones would exclude many non-targets from targets. However, once the remaining proximity zones are defined, provisions must be made for proximal targets that are legitimate, such as those defined by passer-by roles. In such cases, legitimate targets would repeatedly pass by the focus point and would need to be defined based on other criteria, such as the amount of time that they are in the area (loiter time), their proximity range to the target (a drive by shooting), or through exclusionary routines such as those provided by intelligence sources external to the movement algorithm (i.e., known terrorist databases); the latter is more of a pass/fail type of classification.

In the exact same way, the passage of the same person by the same target several times without a discernable purpose could be easily construed as “scouting behavior” and thus create a new algorithmic path for analysis. Comparison of an ambulatory person’s behavior both before and after he or she approaches a target could also supply clues; for example, were they meeting someone before or after the pass by the target? Did other personnel give them something before or after passing the target? The involvement of multiple actors vs. a single person could lead to an even stronger case of conspiracy to act.

It might also be possible to relocate or emplace potential targets away from areas of potential ingress and egress using this process in reverse, i.e., to understand how a target is made to be “easy” vs. “hard” in the eyes of an aggressor. This is similar to locating a castle on top of a mountain surrounded by a moat: the defense is to preclude an easy attack based on geography, a principle that could be used in reverse by a-priori running a purposive movement detection algorithm in reverse.

Incidentally, a BFT-type tracker system could help to eliminate false positives from personnel who would regularly commute near the proposed target even though it is subject to the physical security risk of those BFT trackers being taken by non-approved personnel. The carrying of electronic identification aids by non-threat personnel could quickly narrow the field of likely candidates, with the caveat that the physical security of those identification aids is critical to their effectiveness.

These examples show how large amounts of data could be fused by sensors (a common technique currently) and developed into predictive algorithms that could instantly provide personnel with filtered and condensed information on any array of possible aggressor personnel. The basis of this approach is based on repeatable physical behaviors in association with criterion that could be indicative of purpose or even past history.

5. Results

Many surveillance systems have the potential to integrate mixed sensor feeds with human purposive movement algorithms. They vary in sophistication and intent from simple GMTI trackers to systems that already contain some identification routines based on movement criterion, such as ground or air speed. Some examples are shown in the following figures.

This developmental U.S. Joint Forces Command interface (circa 2005, figure 1) used multiple electro-optical sensor feeds from Unmanned Aerial Systems projected on a digital terrain map. It also used ICONic coding to show targets of interest (black hexaforms and light-blue conic symbols, as well as areas of interest) as blue, red, and green lines. In addition, this interface allowed users to selectively view video feeds as subwindows within the main screen view. These subfeeds were brought in from multiple Unmanned Aircraft Systems (UASs) and are shown in figure 1 as three separate views, two of which are presented as side views overlaid on the map and one of which is a downward view shown in the upper-right corner of the screen. As such, this projective system was very effective at raising physical situation awareness of the battlefield; however, it was not capable of automatically analyzing movement patterns because it did not have an active radar sensor feed.

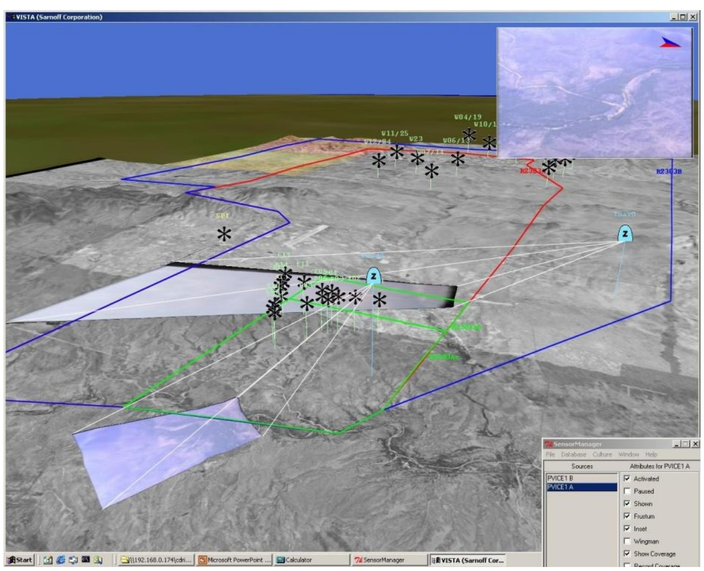

Figure 1. Forward Look system interface.

The interface for the Ground Master radar (circa 2008, figure 2) used a digital terrain map similar to Forward Look and military mapping products such as FalconView[*]. Unlike other digital maps, the Ground Master interface contained automated detection algorithms that, based on radar return information, could classify a target as an individual, an animal, or a vehicle. It also had an information display window (upper left of display) that showed ground movement speed and direction for cursor-designated targets; this display provided further information to place those types of targets into simple categories such as animal, person, vehicle, or low-flying aircraft.

Figure 2. Ground Master radar system.

Sentinel Hawk (circa 2010, figure 3) provided imagery from multiple UASs but contained more sophisticated and automated detection routines based on radar returns and change detection algorithms. Both of the Sentinel Hawk screens shown in figure 3 have ICONIC GMTI-type symbology that was automatically applied based on sensor returns.

The top half of the screen displays brown boxes showing noncoherent change detection (objects on the ground that have moved within a short period of time). The lower screen image shows designated targets (usually small boxes with circular UAS orbits around them that are being surveilled). Each UAS orbit has its color-coded UAS symbol attached. In this system, ground-moving target indicators were automatically applied and manually designated by the operators. These GMTI returns, however, were not intelligent-aided target designators; they were designated by matching simple movement criterion that was preset into the system, such as object presence or absence or object movement rates.

---

[*] FalconView is a trademark of the Georgia Tech Research Corporation.

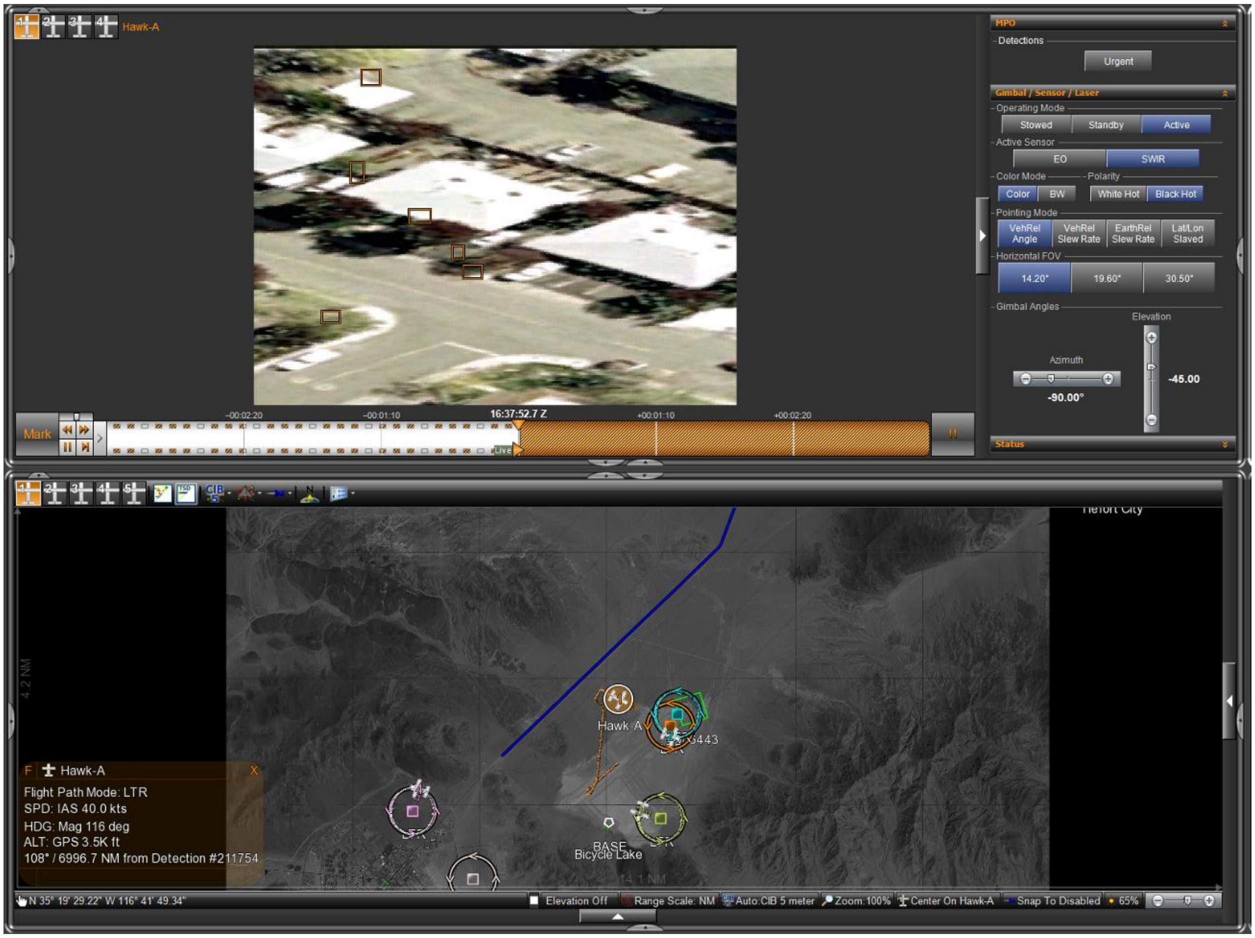

Figure 3. Sentinel Hawk system interface.

Figure 4 is an example of an interface that provides GMTI tracking and has the resolution ability to discern targets in close proximity to each other—for example, vehicles whose movement paths may be converging or lie in close proximity to each other. In this Vehicle and Dismount Exploitation Radar/VADER Exploitation Ground Station (VADER/VEGS) screen sample, radar target hits on a moving vehicle are color coded and overlain on a topographic map. The VADER/VEGS system (circa 2011) shows several of its features in this screen capture. At first glance, this system appears to be like a standard GMTI system screen capture; it does involve predictive elements not found on previous GMTI legacy systems.

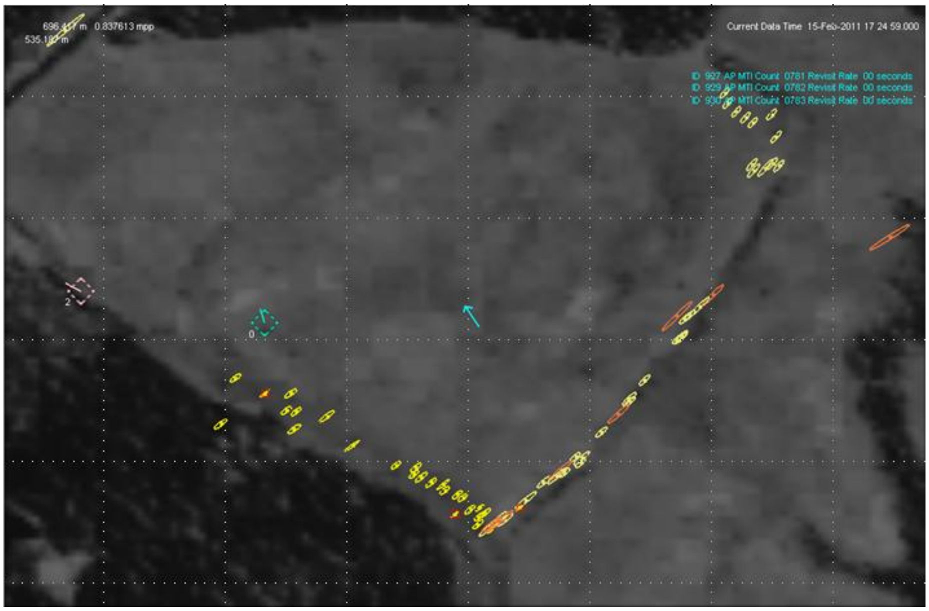

Figure 4. VADER/VEGS system interface.

The moving target is designated by the yellow GMTI icons that show the travel path on a dirt road. In addition, the overall (vector) trend of the target movement is predicted by a simple trending algorithm (for recent active hits). This movement is shown by the turquoise arrow and the dashed turquoise box with a line segment contained within, showing the direction of a dropped track (i.e., the last track in the series). The screen shows an overall object direction (trend) as well as a specific trend of movement based on the last recorded radar hit on the object. It also shows a pure predictive track in the dashed pink box based on a predictive track being estimated by recent historical radar return data relating to direction and speed over a given time frame (which in this case is shown by the last 20 radar [yellow] hits on the screen). However, while this predictive system creates a graphic projection of movement, it does not consider topographic limitations to that movement. The purposive movement theory would require that the features of the topography be input into the predictive model as a matter of course based on the system being tracked. For example, if the target were an individual person, that person would have a greater degree of freedom in movement than if the target were a vehicle conveyance. Considering the terrain features of the area in question is critical to understanding the ability to both classify a target into a group and predict the path of that target.

In this system, predictive algorithms provide a possible future path to the target that allows the operator to anticipate future attacker travel based on past travel patterns. The human purposive movement theory illustrates a current application of some of the movement precepts described earlier in this report, albeit on a limited basis. The differences between the systems listed previously are that one tracks and locates movement, one projects to a minor degree future travel based on historic returns, and one accurately qualifies a target based on simple movement characteristics into several exclusive categories.

6. Discussion

While much of the existing sensor fusion and tracking technology is important, it typically cannot answer goal-oriented questions, such as what might be the purpose of these various movement activities? The theory of purposive movement is attempting to equate movement of what appears to be random physical activities to goals that are defined by the observer; the theory is attempting to answer not only the "what" questions, but also the "why" questions associated with human activities involving movement.

Initially, the number of variables that could be input to an algorithm may seem unmanageable. This would certainly be the case if the human were involved directly in the computing loop; however, a digital computer-based sorting and filtering scheme could reduce that limitation. In the case of multiple targets, current technology can easily represent hundreds or thousands of radar returns on a computer-generated map. That number of targets is clearly unmanageable by an operator looking at the targets and trying to determine intent or purpose. The algorithms almost instantly reduce the volume of targets based on the preprogrammed criterion mentioned in this text. By recursively eliminating variables that do not present desired behavior (proximity, closure path, and closure rate), we can reduce hundreds of "potential attackers" to a handful. Of that subset, other routines, as mentioned previously, further reduce variability and the number of possible attackers.

When placed into a look-up table format or defined by if-then statements, the process of digital selection can ultimately provide a small number of very likely potential attackers of which a human operator can selectively examine using the micro-level sensor systems available. This systematic reduction in possible causal agents applies powerful machine logic without having an "intelligent machine." Rather than creating an artificial intelligence system that needs to learn and understand the implications of thousands or millions of variables, this theory provides a brute force reduction in possible targets, allowing the full intuitive and intelligence capabilities of the human to come into effective play on a reasonable set of choices provided by a system.

7. Conclusions

It is important to consider the implications of this theory in reducing human workload, increasing theatre-wide situation awareness, and providing a rapid response to a complex situation. If the system had secondary ties to intrusive biometric systems, intelligence databases, and other sources of information, the operator could be dramatically more effective in leveraging his or her abilities in a difficult setting.

8. Recommendations

The creation and testing of a system as suggested by this theory could increase the ability to fuse complex physical actions, biometrics, and intelligence databases into an effective aid that could detect the intent of persons unknown to an individual in relation to the aggressive actions that they might perform. This system could be a considerable force multiplier in the process of determining human intent from repeatable, quantifiable behaviors that must be present to instigate an aggressive action.

9. References

Bandura, A. *Social Foundations of Thought and Action: A Social Cognitive Theory*. Prentice-Hall: Englewood Cliffs, NJ, 1986.

Fitts, P. M. The Information Capacity of the Human Motor System in Controlling the Amplitude of Movement. *Journal of Experimental Psychology* **June 1954**, *47* (6), 381–391. (Reprinted in *Journal of Experimental Psychology: General* **1992**, *121* (3), 262–269.)

Fitts, P. M.; Peterson, J. R. Information Capacity of Discrete Motor Responses. *Journal of Experimental Psychology* **1964**, *67* (2), 103–112.

General Dynamics Web site. http://www.gdc4s.com/ (accessed March 2012).

Gilbreth, F. B. *Motion Study: A Method for Increasing the Efficiency of the Workman*; D. Van Nostrand: New York, 1910. http://ia600302.us.archive.org/24/items/studymotion00gilbrich/studymotion00gilbrich.pdf (accessed January 2012).

Gilbreth, F., Jr.; Carey, E. G. *Cheaper by the Dozen*; Harper Collins: New York, 1948.

Hartley, R. V. L. Transmission of Information. *Bell System Technical Journal* **1928**, *7* (3), 535–563.

Hick, W. E. On the Rate of Gain of Information. *Quarterly Journal of Experimental Psychology* **1952**, *4*, 11–26.

Hunn, B.; Schweitzer, K. SBInet. Block 1 test results, Human Engineering Summary, part of the Department of Homeland Security report developed by the U.S. Army Research Laboratory, Ft. Huachuca Field Element, for inclusion into the summary report on the SBInet Block 1 system. Aberdeen Proving Ground, MD, December 2011.

Hyman, R. Stimulus Information as a Determinant of Reaction Time. *Journal of Experimental Psychology* **1953**, *45*, 188–196.

Kahneman, D.; Tversky, A. Prospect Theory: An Analysis of Decisions Under Risk. *Econometrica* **1979**, *47* (2), 263–291.

Locke, E. A.; Latham, G. P. *A Theory of Goal Setting and Task Performance*; Prentice Hall: Englewood Cliffs, NJ, 1990.

Newell, F. W.; Donders, F. C. *American Journal of Ophthalmology* **1989**, *107* (6), 691–693.

Roath, L. R.; Krueger, W. C. Cattle Grazing and Influence on a Forested Range. *Journal of Range Management* **1982**, *35*, 332–338.

Senft, R. L.; Rittenhouse, L. R.; Woodmansee, R. G. The Use of Regression Equations to Predict Spatial Patterns of Cattle Behaviour. *J. Range Manage* **1983**, *36*, 553–557.

Shannon, C. Communication Theory of Secrecy Systems. *Bell System Technical Journal* **1949**, *28* (4), 656–715.

Wolfram Research Web site. http://scienceworld.wolfram.com/biography/Donders.html (accessed 12 March 2012).

INTENTIONALLY LEFT BLANK.

List of Symbols, Abbreviations, and Acronyms

BFT	Blue Force Tracker
COP	Common Operating Picture
DHS	Department of Homeland Security
DMTI	Dismount Moving Target Indicator
GMTI	Ground Moving Target Indicator
MTI	Moving Target Indicator
SBInet	Secure Border Initiative Project
UAS	Unmanned Aircraft Systems
VADER	Vehicle and Dismount Exploitation Radar
VEGS	VADER Exploitation Ground Station

NO. OF COPIES	ORGANIZATION
1 (PDF only)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FORT BELVOIR VA 22060-6218
1	DIRECTOR US ARMY RESEARCH LAB IMNE ALC HRR 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB RDRL CIO LL 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB RDRL D 2800 POWDER MILL RD ADELPHI MD 20783-1197

NO. OF COPIES	ORGANIZATION
1	ARMY RSCH LABORATORY – HRED RDRL HRM C A DAVISON 320 MANSCEN LOOP STE 115 FORT LEONARD WOOD MO 65473
2	ARMY RSCH LABORATORY – HRED RDRL HRM DI T DAVIS J HANSBERGER BLDG 5400 RM C242 REDSTONE ARSENAL AL 35898-7290
1	ARMY RSCH LABORATORY – HRED RDRL HRS EA DR V J RICE BLDG 4011 RM 217 1750 GREELEY RD FORT SAM HOUSTON TX 78234-5002
1	ARMY RSCH LABORATORY – HRED RDRL HRM DG K GUNN BLDG 333 PICATINNY ARSENAL NJ 07806-5000
1	ARMY RSCH LABORATORY – HRED ARMC FIELD ELEMENT RDRL HRM CH C BURNS THIRD AVE BLDG 1467B RM 336 FORT KNOX KY 40121
1	ARMY RSCH LABORATORY – HRED AWC FIELD ELEMENT RDRL HRM DJ D DURBIN BLDG 4506 (DCD) RM 107 FORT RUCKER AL 36362-5000
1	ARMY RSCH LABORATORY – HRED RDRL HRM CK J REINHART 10125 KINGMAN RD BLDG 317 FORT BELVOIR VA 22060-5828
1	ARMY RSCH LABORATORY – HRED RDRL HRM AY M BARNES 2520 HEALY AVE STE 1172 BLDG 51005 FORT HUACHUCA AZ 85613-7069
1	ARMY RSCH LABORATORY – HRED RDRL HR MP D UNGVARSKY POPE HALL BLDG 470 BCBL 806 HARRISON DR FORT LEAVENWORTH KS 66027-2302

NO. OF COPIES	ORGANIZATION
1	ARMY RSCH LABORATORY – HRED RDRL HRM DQ M R FLETCHER NATICK SOLDIER CTR AMSRD NSC WS E BLDG 3 RM 343 NATICK MA 01760-5020
1	ARMY RSCH LABORATORY – HRED RDRL HRM AT J CHEN 12350 RESEARCH PKWY ORLANDO FL 32826-3276
1	ARMY RSCH LABORATORY – HRED RDRL HRM AT C KORTENHAUS 12350 RESEARCH PKWY ORLANDO FL 32826
1	ARMY RSCH LABORATORY – HRED RDRL HRM AS C MANASCO SIGNAL TOWERS BLDG 29808A RM 303A FORT GORDON GA 30905-5233
1	ARMY RSCH LABORATORY – HRED RDRL HRM CU 6501 E 11 MILE RD MS 284 BLDG 200A 2ND FL RM 2104 WARREN MI 48397-5000
1	ARMY RSCH LABORATORY – HRED FIRES CTR OF EXCELLENCE FIELD ELEMENT RDRL HRM AF C HERNANDEZ 3040 NW AUSTIN RD RM 221 FORT SILL OK 73503-9043
1	ARMY RSCH LABORATORY – HRED RDRL HRM AV S MIDDLEBROOKS 91012 STATION AVE FORT HOOD TX 76544-5073
1	ARMY RSCH LABORATORY – HRED RDRL HRM CN R SPENCER DCSFDI HF HQ USASOC BLDG E2929 FORT BRAGG NC 28310-5000
1	ARMY RSCH LABORATORY – HRED HUMAN RSRCH AND ENGRNG DIRCTRT MCOE FIELD ELEMENT RDRL HRM DW E REDDEN 6450 WAY ST BLDG 2839 RM 310 FORT BENNING GA 31905-5400

NO. OF COPIES	ORGANIZATION
1 (CD only)	ARMY G1 DAPE MR B KNAPP 300 ARMY PENTAGON RM 2C489 WASHINGTON DC 20310-0300
	ABERDEEN PROVING GROUND
5	DIR USARL RDRL HR L ALLENDER T LETOWSKI RDRL HRM P SAVAGE-KNEPSHIELD RDRL HRM A D HARRAH RDRL HRS D B AMREIN